Using Multi-Scale Dynamic Rupture Models to Improve Ground Motion Estimates

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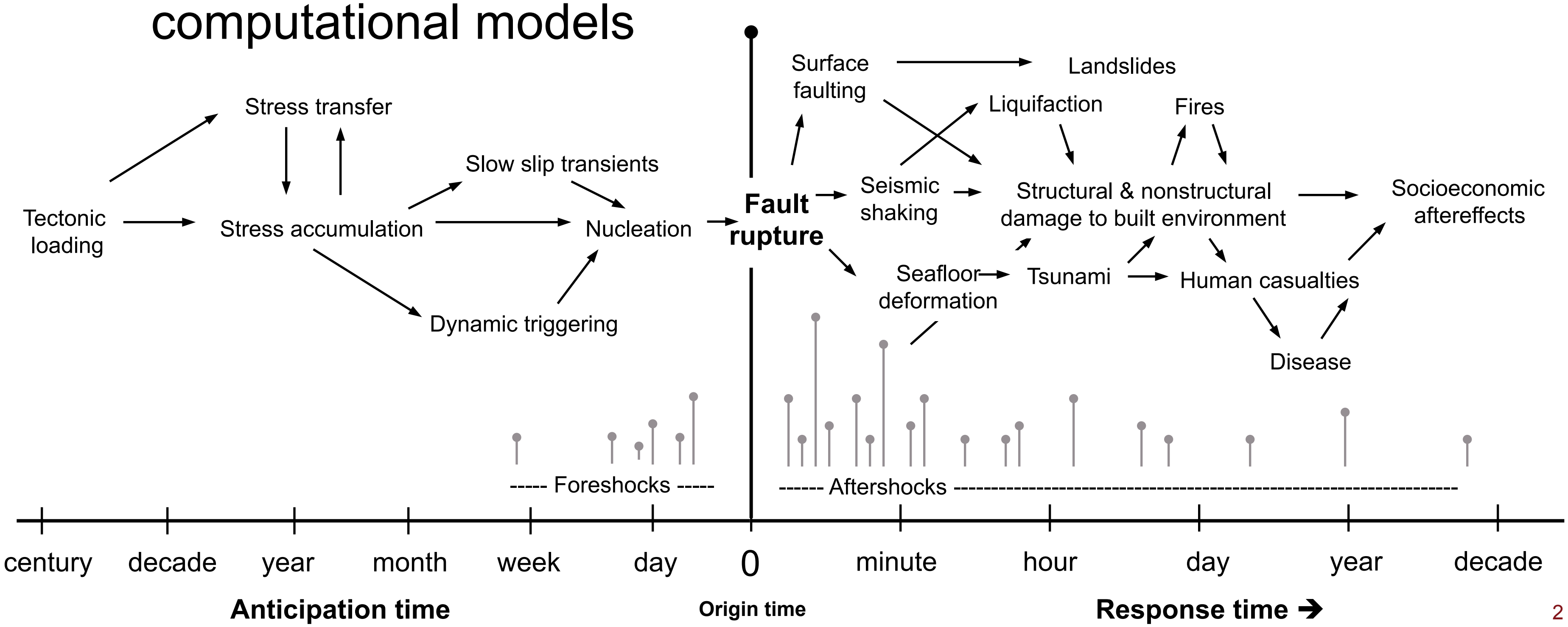
an NSF+USGS center

Southern California Earthquake Center

- Collaboration of 600+ scientists at 60+ institutions
- SCEC conducts earthquake system science
  - Many physical phenomena involved
  - Community Modeling Environment (CME) improves computational models



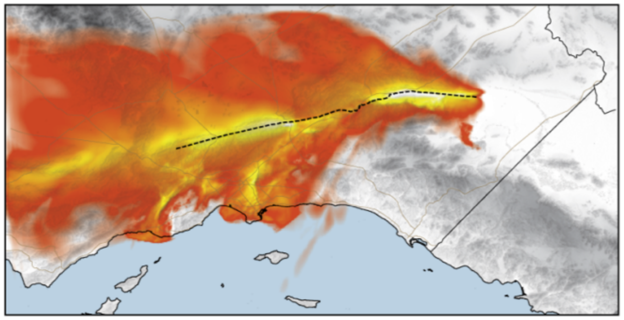
Science Goals

- Dynamic ruptures
  - Improve understanding of physics during ruptures
  - Increase range of length scales
    - Friction at millimeter scale to fault 100s of kilometers long
  - Increase rupture description valid frequency from 2 to 10 Hz
- Wave propagation
  - Validate earth structural model
  - Simulate earthquakes at higher frequencies with improved rupture descriptions
    - 5 story -> 1 story buildings
- Probabilistic seismic hazard analysis (PSHA)
  - Perform physics-based PSHA for all California

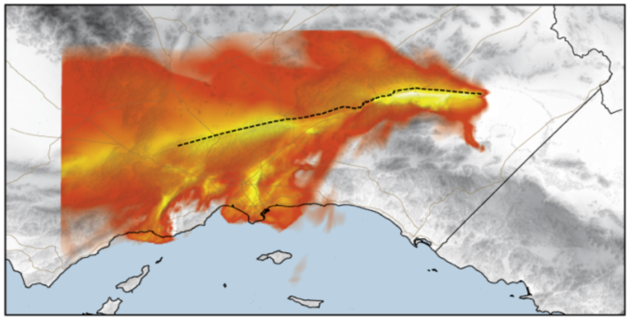
Validation

- SCEC community has multiple codebases
- Important to validate results across multiple codes
- Plan to continue cross-code validation on Mira

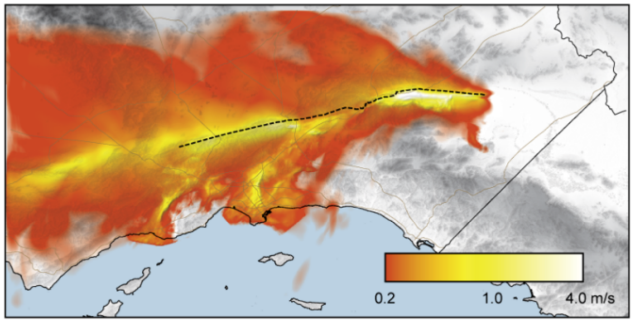
Peak ground velocities for a M7.8 San Andreas scenario with 3 independent codes



Finite element (CMU)



Finite difference (URS)



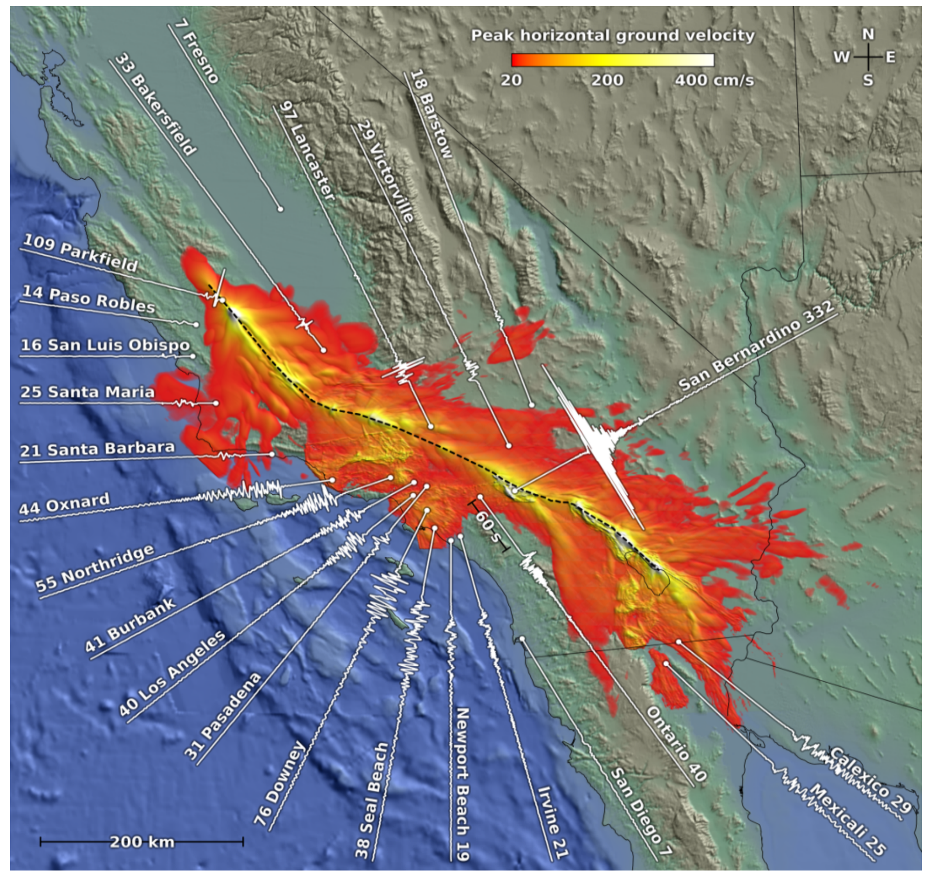
Finite difference (AWP-ODC)

Codes

- AWP-ODC
  - Seismic wave propagation, dynamic planar ruptures
- SORD
  - Wave propagation, dynamic ruptures
- Ma-FE
  - Dynamic ruptures
- CyberShake
  - Combines results of other codes for seismic hazard

AWP-ODC

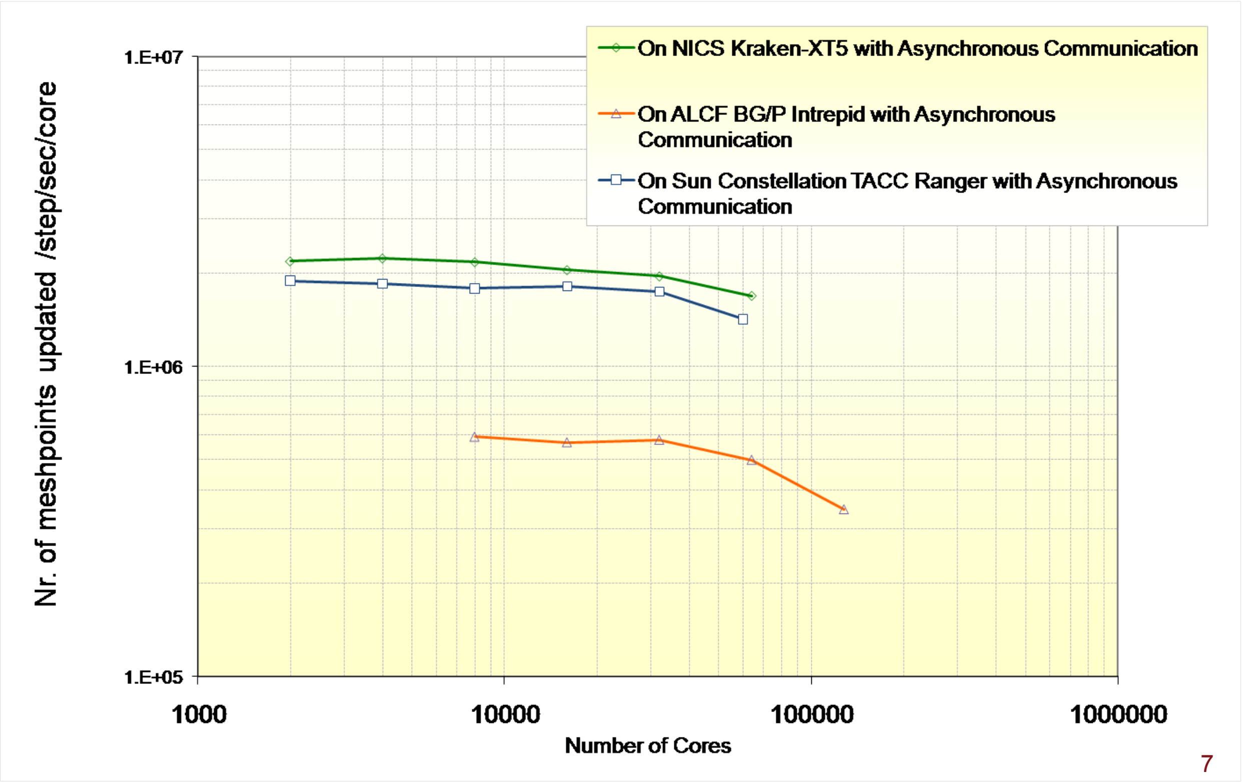
- Wave propagation and dynamic rupture code
  - Staggered-grid, finite difference
- Numerous optimizations
  - Large input files (5+ TB) read contiguously by processor subset and distributed
  - Asynchronous MPI communication
  - Rank placement onto cores
  - Single-core optimizations
    - Cache blocking
    - Loop unrolling
    - Arithmetic optimization



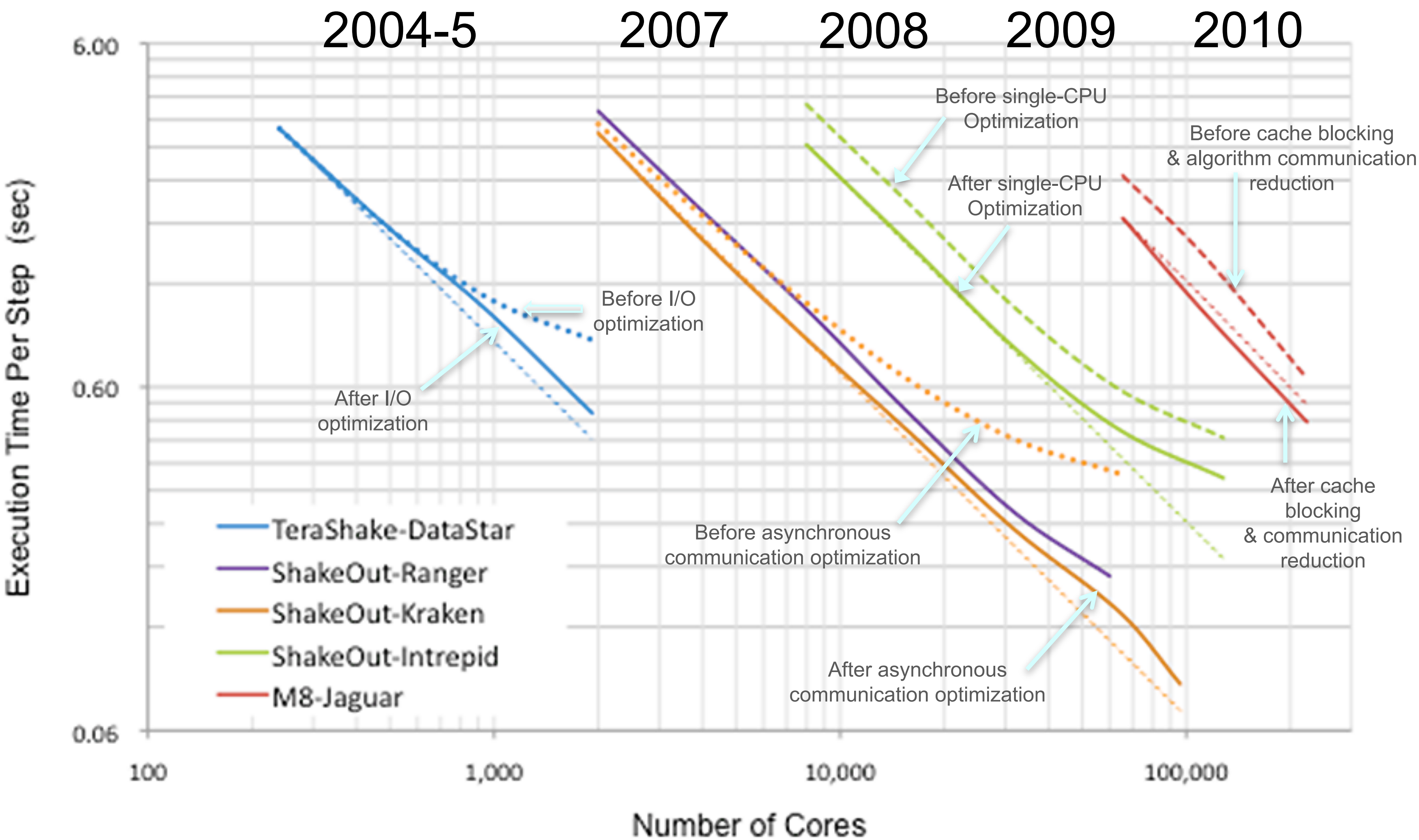
Peak horizontal ground velocities from a M8 scenario on the San Andreas Fault

AWP-ODC Performance

- Run successfully on Jaguar, Intrepid, Ranger
- Scales well (superlinear) on 230K cores (5.6 million SUs)
- Adding support for scalable fault-tolerance
- Eager to test on BG/Q hardware
  - OpenMP/MPI version
- Supporting volume I/O is a challenge
  - 2 trillion mesh points in 2012

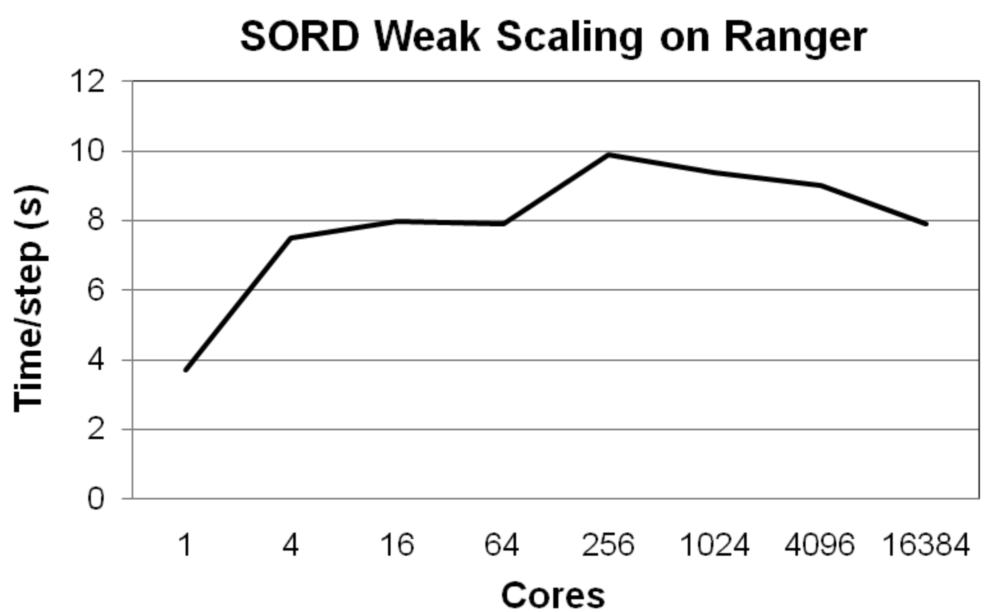


Evolution of AWP-ODC Performance



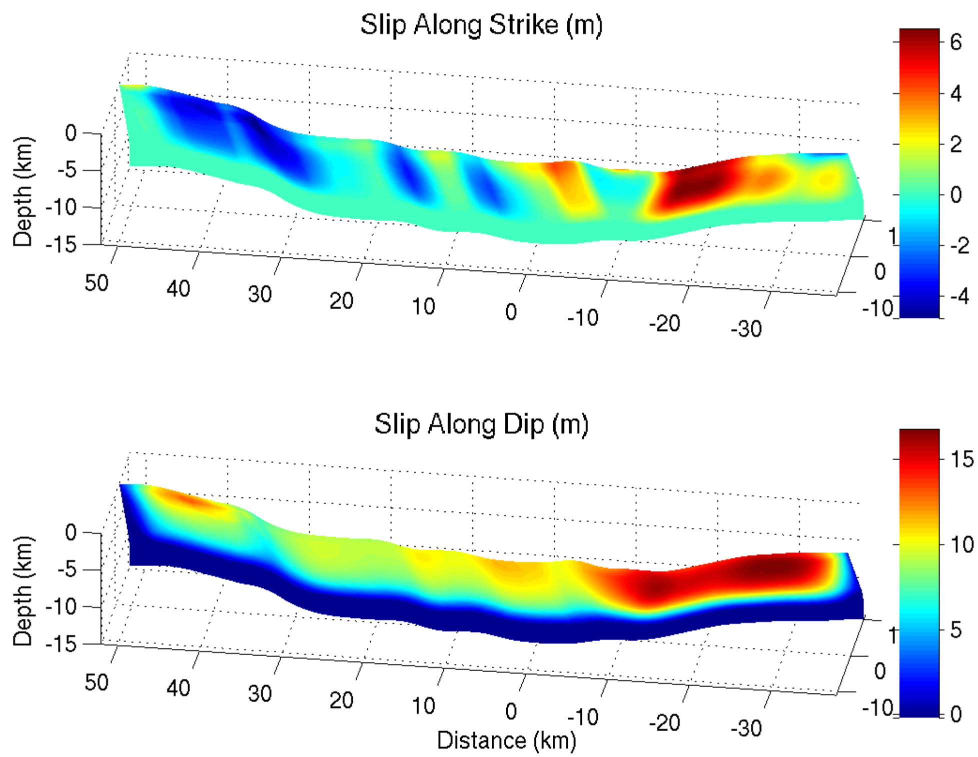
SORD

- Wave propagation and dynamic rupture code
  - Hexahedral mesh (surface topography)
- Tested to 16k cores at TACC Ranger
- Next 6 months
  - Communication/ computation overlap
  - Contiguous reading of input with redistribution (similar to AWP-ODC)



Ma-FE

- Dynamic rupture code
  - Finite element
  - Hexahedral mesh (topography, non-planar faults)
- Can explore fault physics
  - Complex, branching fault structures
  - Friction laws
  - Non-linear plastic yielding
  - Rough fault surfaces



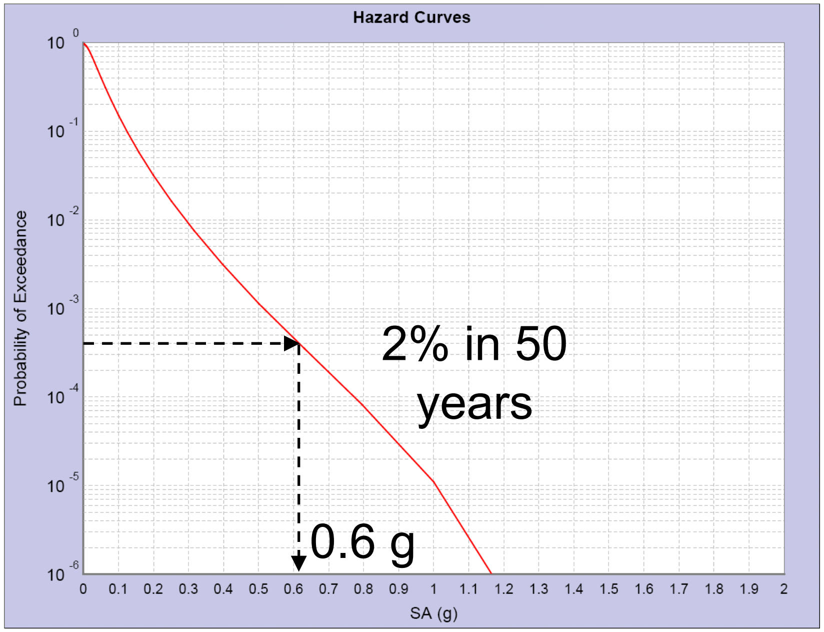
Final slip from dynamic rupture simulation of M7.7 on Sierra Madre/Cucamonga faults

Ma-FE performance

- Recently implemented parallel versions
  - 72% efficiency from 16 to 16K cores on Ranger
  - Load-balancing issues
- Next 6 months
  - Parallel I/O
  - Asynchronous communication
  - Single-CPU optimizations
- Ultimately move to 2 trillion mesh point simulations

Seismic Hazard

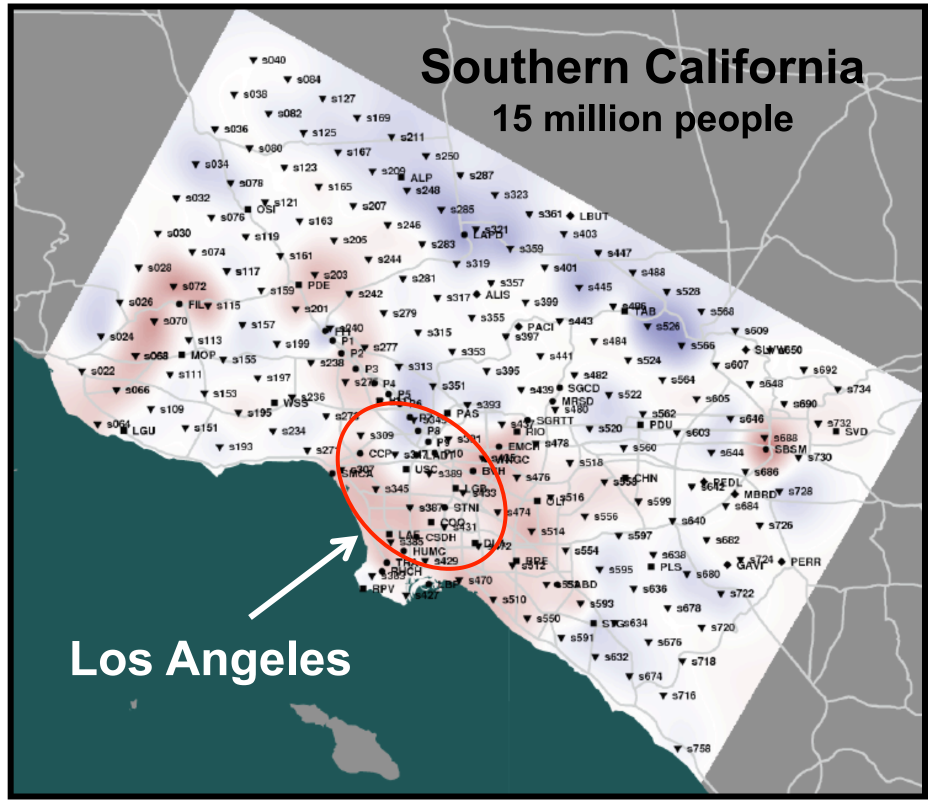
- Determine probabilities of expected ground motion over time period
- Useful for building codes, insurance rates
- Multiple inputs required
  - 3D structural model of earth
  - Seismic wave propagation
  - Descriptions of rupture slip



Hazard curve for downtown Los Angeles

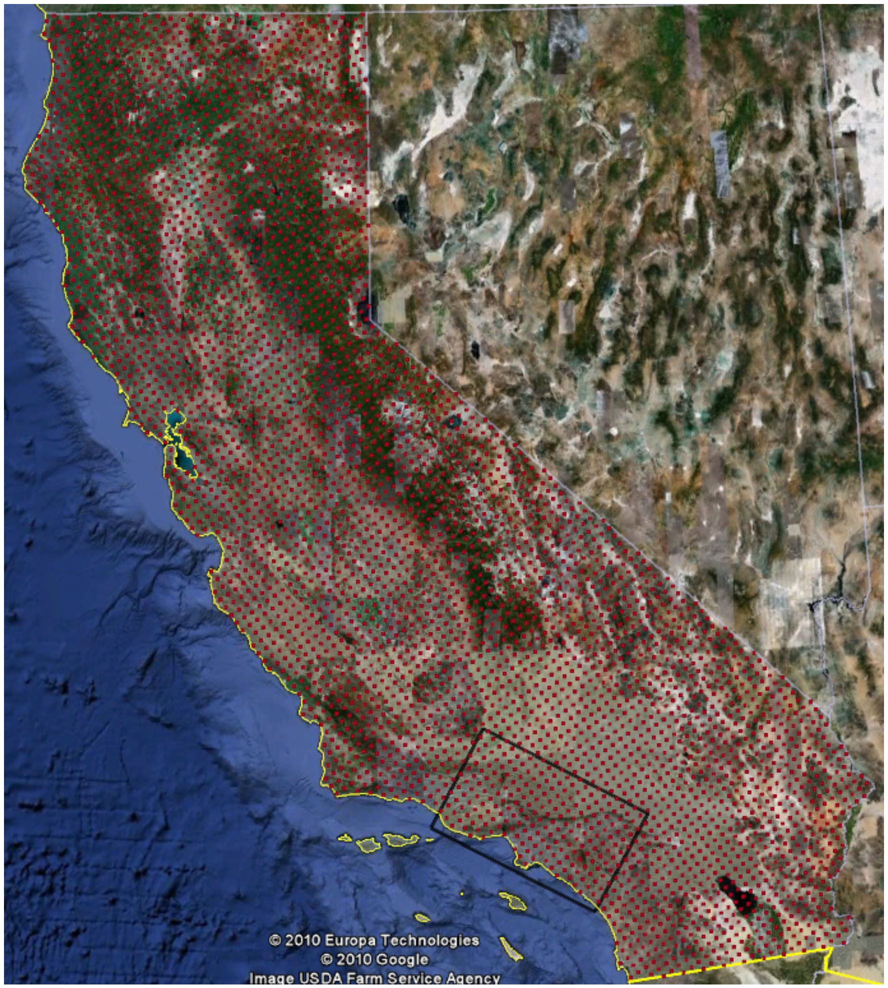
CyberShake

- Identify relevant earthquakes
  - 400,000 per site
- Wave propagation
  - Relationship between fault motion and ground motion
- Determine shaking from each possible earthquake
- Use probabilities to determine site hazard
- Results for each site combined to determine regional hazard



Difference between physics-based CyberShake and empirically-based attenuation results for Southern California. Red shows areas where CyberShake predicts higher hazard, blue lower.

CyberShake



Each dot represents a site to generate a CyberShake hazard curve for. The black box represents the part of Southern California considered in the previous runs.

- Calculated 223 sites on up to 15k cores on Ranger (5 million SUs)
  - Next is ~4000 sites for all-CA
- Next 6 months
  - Use AWP-ODC to perform wave propagation
    - Parallelism from 400 cores -> ?
    - Increase frequency to 1 Hz
  - Improve caching
  - Use dynamic rupture results to generate improved rupture descriptions

Questions?

SCEC
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ISI
Information Sciences Institute

TeraGrid™

SDSC
SAN DIEGO SUPERCOMPUTER CENTER

NICS

National Science Foundation

TACC

USGS
science for a changing world

OLCF
Oak Ridge Leadership Computing Facility

NCSA

USCGRID